Wood and Other Renewable Resources (Subject Editor: Jörg Schweinle)

Wooden Building Products in Comparative LCA

A Literature Review

Frank Werner[1]* and Klaus Richter[2]

[1] Environment & Development, Waffenplatzstrasse 89, 8002 Zurich, Switzerland
[2] Empa, Swiss Federal Laboratories for Materials Testing and Research, Wood Laboratory, Ueberlandstrasse 129, 8600 Duebendorf, Switzerland

***Corresponding author** (frank@frankwerner.ch)

DOI: http://dx.doi.org/10.1065/lca2007.04.317

Please cite this paper as: Werner F, Richter K (2007): Wooden Building Products in Comparative LCA. A Literature Review. Int J LCA 12 (7) 470–479

Abstract

Background, Aim and Scope. We revised the results of approx. 20 years of international research on the environmental impact of the life cycle of wood products used in the building sector compared to functionally equivalent products from other materials.

Main Features. Original studies either technical reports or scientific papers in English or German were considered. This literature was obtained via an extensive literature review (February 2006), via a consultation of compilations of life cycle assessments (LCA) of wood products (e.g. elaborated during the COST action E9) and from secondary literature. The resulting list of literature is considered to be quite complete and therefore covers the most relevant original comparative LCA studies of wood products in the building sector in Europe, Northern America and Australia. The documentation of the studies differs considerably in terms of completeness (life cycle stages included, assessment methods), transparency (description of methodological assumptions, characteristics of the products, available data, etc.) and scientific rigor (e.g. related to the functional equivalency). All encountered original studies are cited and their scope and transparency is shortly described. For the environmental ranking of wood products compared to functionally equivalent products, only quantitative, transparently described studies with no obvious methodological flaws were included, preferably covering the whole life cycle and conducted according to the ISO series of standards 14'040ff. For the assessment, the contribution of each product to an impact category was compared to the mean of all functionally equivalent products included in a study.

Results and Discussion. Among the most important results are: fossil fuel consumption, potential contributions to the greenhouse effect and quantities of solid waste tend to be minor for wood products compared to competing products; impregnated wood products tend to be more critical than comparative products with respect to toxicological effects and/or photosmog depending on the type of preservative; incineration of wood products can cause higher impacts of acidification and eutrophication than other products, whereas thermal energy can be recovered; although composed wood products such as particle board or fibreboard make use of a larger share of wood of a tree compared to products out of solid wood, there is a high consumption of fossil energy associated with the production of fibres and particles/chips as well as with the production of glues, resins, etc. In LCAs of whole buildings, the materials used outside the areas of applicability of wood dominate the environmental profile of the building; current methods used for the impact assessment do not allow to consider (also favourable) impacts of forests, such as land occupation, impacts on biodiversity, purification of air, etc.

Conclusions. Wood products that have been installed and are used in an appropriate way tend to have a favourable environmental profile compared to functionally equivalent products from other materials. For the dispersion and application of these conclusions, it is necessary to adapt LCA to a form, which can be used on a regular basis for the decision making of different actors in the construction sector.

Perspectives. LCA methodology in general (the series of standards ISO 14'040ff) and for the environmental assessment of wood products in particular have been developed and consolidated considerably in Europe and Northern America during the last decade; the more and more representative and reliable LCI data for wood products and competing products has become available. For the future use of the environmental value of wood products within sustainable development, the general perception of the beneficiary use of wood products has to be increased at various stages of decision-making.

Keywords: Building products; buildings; comparative LCA; Life Cycle Assessment (LCA); wood

Introduction

For this paper we revised and assessed the results of around 20 years of international research on the environmental impact of the life cycle of wood products used in the building sector compared to functionally equivalent products from other materials.

As in other industrial sectors, the idea to assess environmental impacts of wood products arose during the early 70th of the last century as a consequence of the two oil crisis. Consequently, early research and case studies focused on energy consumption during production processes (Boyd et al. 1976, Ressel 1986). In the following years, this focus was extended towards covering more environmental aspects and integrating the complete life cycle of wood products.

The process of standardizing environmental life cycle assessment (LCA) under the Society of Environmental Toxicology and Chemistry (SETAC) (Consoli et al. 1993) and under the International Standardization Organization ISO

© 2007 ecomed publishers (Verlagsgruppe Hüthig Jehle Rehm GmbH), D-86899 Landsberg and Tokyo • Mumbai • Seoul • Melbourne • Paris

(the series standards ISO 14'040ff) as well as various European initiatives for the consolidation of LCA for silvicultural processes and wood products have established a concerted framework for LCA of wood products (e.g. Erlandson 1996, Fava et al. 1996, Esser et al. 1999, Jungmeier 2001, Jungmeier et al. 2001, Karjalainen et al. 2001, Werner 2001, Jungmeier et al. 2002a, 2002b, Werner 2002, Werner et al. 2002, Werner et al. 2007).

This methodological development went in line with various initiatives to elaborate life cycle inventory (LCI) data for the processes along the wood processing chain in various European countries and Northern America. Nowadays, LCA assessment of product can be based on an extensive and reliable set of LCI data for forestry processes and the production, use, and disposal of wood products (e.g. Schwaiger et al. 2001, Werner et al. 2003, Lippke et al. 2004).

1 Scope and Methodology

This paper compiles the comparative LCA studies of wood based building products compared to functionally equivalent products out of other materials that have been published since the development of this instrument of environmental management (since ± 1990). The environmental impacts of each product are compared to the mean impacts of all functionally equivalent products investigated in the same study. Original studies as technical reports or scientific papers in English or German were considered. This literature was obtained via an extensive literature review (February 2006), via the consultation of compilations of LCA studies of wood products (e.g. elaborated during the COST action E9) or taken from secondary literature (e.g. Townsend et al. 2002, LeVan 1995, Richter et al. 1996b, FAO 2002, Taylor et al. 2003). For the literature search, a Web-SPEARS-based clustered search was conducted in around 150 databases (among them: ISI Web of science, Current Contents, Science Direct, BIOSIS, CABI, etc. using keywords such as LCA, life cycle assessment, environmental, wood, comparative, flooring, doors, sleepers, ties, parquet, building, etc. and combinations thereof. The resulting list of literature is considered to be quite complete and covers the most relevant original comparative LCA studies of wood products in the building sector in Europe, Northern America and Australia.

The encountered literature ranges from 20-page licentiate thesis to research reports of some hundred pages. As a consequence, the literature differs considerably in terms of completeness (life cycle stages included, assessment methods), transparency (description of methodological assumptions, characteristics of the products, available data, etc.) and scientific rigor (e.g. related to the functional equivalency); the results of these studies can therefore not be compared across studies and product groups. In the following Section 2, all encountered original studies are cited and their scope and transparency is shortly described. In Section 3 – summarizing the environmental ranking of wood products compared to functionally equivalent products of alternative materials – only quantitative, transparently described studies with no obvious methodological flaws have been included, preferably covering the whole life cycle and conducted according to the ISO series of standards 14'040ff. Section 4 concludes and Section 5 provides an outlook on the future role and needs of LCAs of wood products.

In the context of climate change, some scientific studies particularly address the greenhouse gas emissions and/or fossil energy consumption associated with building products (e.g. Pingoud et al. 2002, Buchanan et al. 1999, Sedjo 2002, Buchanan et al. 1994, Koch 1992, Marcea et al. 1992, Suzuki et al. 1995, Werner et al. 2006b). It is outside the scope of this review to compare these references with their particular focus.

Wood is also an important primary material for paper production, packaging and for other applications. For example, Reichart et al. (2001) have assessed the environmental impacts of print media compared to electronic media; different types of packaging materials including different logistic scenarios have been assessed by Hekkert et al. (2000). These studies remain outside the scope of this compilation, which concentrates on building material.

Given the limited size of this paper in view of the large number of products, studies, impact categories, etc. the presentation of each study can only be very short. Interested readers are kindly invited to refer to the original literature for details; an in-depth research report underlying this paper is available in Spanish (Werner 2006).

2 Wooden Building Products in Comparative LCA

2.1 Windows

The environmental impacts related to the life cycle of windows have been analyzed in Asif et al. (2002), Richter et al. (1996c) or Kreissig et al. (1997). The first study assesses window frames made of PVC, aluminium, wood, and wood/aluminium; it considers the frame itself without taking into account the thermal properties of the whole construction including the glazing.

Richter et al. (1996c) cover the same materials but also include steel, stainless steel and non-ferrous windows. Windows of the same size (1650 x 1300 mm girth) for residential houses produced by local SME are compared under Swiss conditions, considering the whole life cycle including the compensation of heat losses with a gas-fired lowNO_x heating system. Mass-based allocation of co-production processes is applied throughout the wood chain; recycling material is modelled with the cut-off procedure. Kreissig et al. (1997) compare aluminium, wood, wood-aluminium and PVC windows; due to different system boundaries the authors abstain from making a direct comparison of these window types. Thus, the study by Richter et al. (1996a) is included in this comparison, as this study is based on functionally equivalent product systems and considers the frame and the glazing. This combination allows the evaluation of environmental effects of the whole construction including its thermal properties. The latter is important because the compensation of heat losses is a major contributor to the environmental profiles of the windows.

2.2 Insulation materials

Since very early in its development, LCA has been used to compare the environmental profile of insulation materials (Ceuterick 1993, Richter et al. 1995, updated by Werner

1998, Mötzl et al. 2000). The following discussion concentrates on the latter two, as Ceuterick (1993) could not be located for this review.

Richter et al. (1995) was one of the first comparative LCAs in Europe. Eight of the most relevant insulation materials for Central Europe are assessed: mineral wool, glass wool, foam glass, extruded polystyrene, vermiculite, perlite, wood fibreboards and flakes of recycled paper. The functional unit is defined as 1 m^3 insulation material and the life cycle is considered 'cradle-to-gate'; allocation or recycling material is based on the cut-off principle. In an update by Werner (1998), the functional unit has been redefined as the quantity of material per m^2 to meet the thermal resistance of R = 2.84 W/m^2K.

Mötzl et al. (2000) base on an extensive data collection of producers in Germany and Switzerland and cover a wide selection of materials and production scenarios for the year 1996. The system delimitation (cradle-to-gate), the functional unit (quantity of material per m^2 to meet the thermal resistance of R = 1.0 W/m^2K) and the allocation rules are quite similar to Richter et al. (1995) and Werner (1998). Given the high similarity of the ranked results, the commonly used materials as assessed by Mötzl et al. (2000) are included in Section 4 as the more recent study.

2.3 Flooring materials

Various studies have been conducted to assess the environmental profile of flooring materials (**Table 1**).

The results of the studies summarized in Table 1 cannot be compared directly for methodological reasons. The studies differ, e.g., in the definition of the functional unit (1 m^2 up to 20 m^2), the processes and life cycle stages included or excluded (e.g. infrastructure, generation of electricity, laying of the floor and its maintenance, etc.), the allocation procedures used for co-production processes, the assumed disposal processes, the electricity mix used, the impact categories used for the impact assessment, etc. (see also Windsperger et al. 1998).

Potting et al. (1996) does not include wooden floors, whereas Werner et al. (1997a) and Nebel et al. (2004) compare wooden floors exclusively. Therefore, these studies lay outside the scope of this paper. Petersen et al. (2003b) compare two alternative floorings for the new airport in Oslo and only consider energetic aspects and a discounted greenhouse gas potential. So, the studies by Günther et al. (1997ba, 1997b) and Jönnson (1999)/Jönsson et al. (1994/1997) are included in the summarizing evaluation in Section 4 as the more representative ones.

Günther et al. (1997a, 1997b) analyze a total of 30 flooring materials for commercial or light industrial applications with an assumed service life of 20 years. All types of floorings as summarized in Table 1 are produced by members of the European Resilient Flooring Manufacturers Institute (ERFMI). The formulation within the same group of flooring materials can vary considerably. For example, accumulated energy consumption for the production and elimination of PVC floorings can fluctuate up to a factor of 3 (Günther et al. 1997a). A 3-layered parquet and a textile carpet are included as references. Landfilling of wood is assumed but too high methane emissions are accounted for (according to Micales et al. 1997). 20 m^2 of flooring materials is considered as the functional unit over the assumed service life of 20 years. The life cycle includes all stages of the life cycle and is representative for the year 1994–96 in Germany. Energy and water consumption for the cleaning of floorings is calculated but not included into the assessment. The study was conducted in conformity with ISO 14'040ff, including three external reviews.

Jönnson (1999)/Jönsson et al. (1994/1997) compare the environmental impacts of 1 m^2 floorings made of linoleum, PVC and non-treated solid wood for domestic use in Sweden associated with one year of service life. Neither the carrying capacity of the materials nor the indoor environmental impacts are taken into account. The floorings are considered 'cradle-to-grave' including the laying of the floors as well as their maintenance; 100% incineration with cogeneration of energy is assumed. Glues are not considered for linoleum and PVC whereas a small quantity is considered for the wooden floor.

The impact assessment of the original studies uses a particular methodology; Windsperger et al. (1998) have recalculated the study by Jönnson (1999) using the CML 92 methodology (Heijjungs et al. 1992). These results are included in Section 4.

2.4 Wall constructions

Meil et al. (1995) assess the life cycle related impacts of a 3m x 30m infill wall designed in wood and the same wall assembly designed in steal; only the structural elements (studs, top and bottom plates, bracing and fasteners) are looked at. No further information on methodological assumptions is provided. Given this lack of transparency, this study is not included in the overall-evaluation in Section 4. The results of this study, however, are in line with the findings by Werner et al. (2001).

Table 1: Comparative LCAs of flooring materials

	Linoleum	PVC foamed	PVC	Wood (parquet)	PA (carpet 'tufting')	Sheep wool	Polyolefins	Rubber	Natural stones
Potting et al. 1996	1	1			1	1			
Werner et al. 1997a				3					
Nebel et al. 2004				7					
Jönsson et al. 1994, 1997, Jönnson 1999	1		1	1					
Günther et al. 1997b, 1997a	various	various	various	reference	reference		various	various	
Petersen et al. 2003a				1					1

Werner et al. (2001) compare the life cycle impacts of four standard constructions of exterior walls as defined in Biedermann et al. (1999): 2-layered brick wall with mineral wool insulation, porous cement wall, wood frame construction and laminated timber board construction. The functional unit of 1 m^2 wall is defined to meet equal thermal standards. Central European processes and technologies are assumed.

2.5 Doorframes

Three types of doorframes of solid wood, particleboard and galvanized steel are compared in Werner et al. (1997b) in conformity with ISO 14'040ff. The doorframes are produced by Swiss or German SME and are designed for interior use with an opening of 80 cm x 200 cm and for walls up to a width of 16 cm, without any specific requirements related to noise reduction or fire resistance. The whole life cycle is considered, including maintenance and recycling; the LCI data of each doorframe is extrapolated to meet the same service life of 60 years. Usually, mass-based allocation is applied for multi-output processes; recycling is modelled with the cut-off procedure.

2.6 Furniture

For furniture, the LCA database is very rudimentary. Bol et al. (1995) assess garden chairs; another study covers different options for TV chassis (Nedermark 1998) and Taylor et al. (2003) draw conclusions on the environmental profile of wood furniture based on LCA studies of wood products in general.

The documentation of the study on garden chairs by Bol et al. (1995) is limited and only qualitative parameters (based on a quantitative assessment) can be found. Nedermark (1998) compares the use of polystyrene, wood (MDF) and wood combined with aluminium as basic materials for the chassis of a television. The documentation of this study is very short, not allowing the assessment of the methodological assumptions or the scope of the life cycle of the products considered. As a consequence, furniture is excluded from the over-all evaluation in Section 3. It has to be concluded that the available comparative LCA studies on furniture are very limited in scope and explanatory power.

2.7 Railway sleepers

A comparative LCA of railway sleepers (*Am.*: ties) made from creosote treated beach, steel and pre-stressed concrete has been conducted by Künniger et al. (1998). As a functional unit, one sleeper including the necessary fixing parts as well as 60 cm of the respective track bed is defined. The LCA is conducted according to ISO 14'040ff and covers the whole life cycle (30 years) under Swiss conditions, including maintenance and disposal of the track bed and the sleepers. Mass-based allocation is applied to model the wood chain; recycling is modelled with the cut-off procedure. The study covers several applications, types of wood preservatives and recycling scenarios; for the over-all evaluation, the standard situation of a track with high strains and creosote type WEI C is considered.

2.8 Utility poles

As one of the first studies in this field Erlandsson et al. (1992) have presented a comparison of utility poles made of creosote (WEI Type B) or CCA (chromium, copper, arsenic) treated solid wood poles, aluminium or reinforced concrete. Unfortunately, the respective study could not be obtained for an in-depth evaluation. Other studies have analyzed wooden poles and posts treated with creosote or CCA, but without taking into account alternative materials (Hillier et al. 1994, Murphey et al. 1995, Hillier et al. 1996, Hillier et al. 1997). The most extensive available comparative LCA of utility poles has been elaborated by Künniger et al. (1997).

Künniger et al. (1997) cover utility poles out of reinforced concrete, solid wood treated with CCF (chromium, copper, fluoride) and tubular steel in their required dimensions, foundations and auxiliary parts for 1 km line medium voltage (0.4 kV) for a specific situation in Switzerland. The whole life cycle is covered, including maintenance, transports, end-of-life processes, etc. up to a lifetime of 60 years, which includes one replacement of the wooden pole. Recycling is assumed for tubular steel and modelled as cut-off. 90% of the wooden poles are incinerated including heat recovery. The remaining 10% are assumed to rot, causing emissions into soil of Cr, Cu, B and F. The large part of the concrete poles is recycled as construction material, part of it is dumped.

2.9 Elements for landscape architecture[1]

Künniger et al. (2000) analyzed a series of elements of landscape architecture to assess the influence of wood preservatives compared to environmental impacts out of alternative products: garden swings for children (construction with two swings; steel or CCF-treated roundwood), palisades (10 m^2; concrete or treated roundwood), blinds (3.24 m^2; lime sand bricks, bricks, concrete or two wooden designs of treated wood, including their respective foundations), constructions for vineyards (material for 1 ha; PVC, steel or impregnated roundwood, including auxiliary material and foundations) and constructions for fruit yards (material for 1 ha; concrete, steel or impregnated roundwood, including auxiliary material and foundations). The whole life cycle is considered, including auxiliary materials, transportation, leaching and waste disposal. Disposal scenarios for Switzerland are assumed: waste incineration including thermal energy recovery for wood and PVC as well as recycling for metals and concrete (modelled cut-off). The production data is taken from various SMEs in Central Europe. For the estimation of leakage of critical elements from wood preservatives and metals coatings, respective tests were conducted at the Swiss Federal Laboratories of Materials Testing and Research (Empa).

2.10 Buildings

During the last years, various authors have assessed the environmental impacts related to the life cycle of buildings.

[1] palisades, swings, support structures for vineyards and fruit yards

Table 2: Comparative LCAs of buildings of different scope, different types of buildings, primary construction materials and assessment methods (buildings considered per type of building)

Studies	Whole life cycle considered	Office build.			Residential houses				Others	Assessment method			
		Steel	Concrete	Wood	Brick/steel	Concrete	Steel	Wood		GHG effects	Primary Energy	CML 1992	Others
Fossdal 1995	?	1	1			1		2			x	x	
Damberger 1995	x				1			2		x	x		
Harris 1999	?				1			1			x		x
Gustavsson 2001	x				1	2		2		x			
Gustavsson et al. 2006	x					2		2		x	x		
Petersen et al. 2003b	x								2 [a]	x [b]			
Börjesson et al. 2000, Lenzen et al. 2002	x		1	1						x			
Buchanan et al. 1999	x	1	1	1					4 [c]	x	x		
Adalberth et al. 2001	x					4					x	x	
Cole 1999	[d]	1	1	1						x	x		
Bowyer et al. 2004, Lippke et al. 2004	[e]					1	1	2			x		x
Goverse et al. 2001	[f]					1		3		x			

[a] beams as constructive elements used in the new Oslo/FI airport
[b] discounting GHG emissions
[c] 2 hostels out of concrete and wood; 2 industrial buildings out of steel and wood
[d] only considering the construction phase
[e] considering the construction phase for 'critical volumina' of air and water (see Meil et al. 1995); considering whole life cycle for primary energy
[f] only considering the production of primary materials

Table 2 presents an overview on LCA studies of buildings found in scientific literatures. This list is considered not to be complete as we assume that the majority of LCAs of buildings is made for the specific use of decision-makers and is not accessible as scientific literature.

Several of these studies focus on GHG emissions without taking into account other environmental aspects. Other studies are documented in a rather rudimentary way. To be in line with the scope of this paper, the results of an extensive research project in the U.S, summarized in Lippke et al. (2004) is included. This study covers the whole life cycle of four residential houses and is documented comprehensively under www.corrim.org.

Bowyer et al. (2004)/Lippke et al. (2004) analyze pairs of average sized, common light weight frame residential constructions (2,225 square feet) for a hot, humid climate in wood or in prefabricated concrete elements and for a cold climate in solid wood (facade out of OSB or plywood) or steel. The study conforms with the series of standards ISO 14'040ff and considers primary energy consumption for the whole life cycle, including also maintenance, use, cleaning, heating/cooling/air conditioning, and disposal; critical volumina of water and air (see Meil et al. 1995) are assessed for the construction only. Local energy generation processes are considered; recycling is modelled cut-off; used wood is dumped. As each pair of houses is designed to meet equal thermal standards, energy for heating/cooling/air conditioning is not considered in Section 3.

For the interpretation of these results, it should be kept in mind that buildings are indeed very complex products. Buildings differ in technical aspects, internal and external appearance, execution of the constructive works, intervals of maintenance and cleaning, behaviour and fashions of its users, etc. This implies that assessing and comparing buildings is based on many assumptions that can have a large influence on the result, e.g. the assumed life time of building elements, the specifications of the equipment for heating, cooling, air conditioning, etc.

3 Results

Table 3 (see **Appendix**) summarizes the results of the above-mentioned studies in the impact assessment methods CML 1992 (Heijungs et al. 1992), Ecoindicator 95 (Goedkoop 1995), cumulated energy demand (non-renewable, renewable, total; no consolidated accounting principles available) and critical volumina (as described in Meil et al. 1995) as used in the studies.

A comparison of options should take into account the various sources of uncertainties and variabilities, e.g. in the definition of the functional unit, the attribution of processes and impacts to a product, in the quality and representativeness of the inventory data or related to an impact category. Such a detailed analysis goes far beyond the data and information available. Instead, the average impact for each impact category and product type is calculated for each study. The relative deviations from the mean for each product and impact category are evaluated according to the classes described underneath Table 3 (see Appendix).

4 Interpretation and Conclusions

During the last 10 years, considerable knowledge has been accumulated on the environmental relevance of various wood products compared to functionally equivalent materials out of competitive materials, particularly in Central and Northern Europe as well as in North America and Australia:

- Wood products tend to have a favourable environmental profile compared to functionally equivalent products out of other materials. Particularly, consumption of non-renewable energy and cumulated energy demand, the potential contributions to the greenhouse effect and the quantities of solid waste are usually minor or very minor compared to competing products. On the other hand, wood products are associated usually with a higher consumption of renewable energy carriers (by nature).
- Impregnated wood products tend to be more critical with respect to toxicological effects and/or photosmog (depending on the type of preservative) than comparative products; new generations of metal-free wood preservatives are promising alternatives with lower environmental impacts.
- Incineration of wood products can cause higher impacts of acidification and eutrophication than other products, although thermal energy can be recovered.
- Composed wood products such as particle board or fibreboard make use of a larger share of roundwood compared to products out of solid wood. However, there is a generally very high consumption of fossil energy associated with the production of fibres and particles/chips as well as with the production of resins, additives, etc.
- In LCAs of whole buildings, the materials used outside the areas of applicability of wood dominate the environmental profile of the building.
- The results of a comparative LCA are very sensitive to methodological decisions, including the selection of an allocation procedure used to model multi-output processes or recycling (Werner 2005, Werner et al. 2007), or assumptions related end-of-life scenarios (e.g. methane emissions from landfilled wood, thermal energy recovery, etc.).
- Existing methodologies do not allow to depict toxicological effects of chemical components of preservatives in an adequate manner because the model structure of an LCA does not have a spatial or temporal resolution.
- In addition to that, current methods used for the impact assessment do no allow to consider (also favourable) impacts of forests, such as land occupation, impacts on biodiversity, purification of air, etc.

The results of an LCA cannot only be used for the comparison of different products or for the in-depth analysis of the environmental profile of a product over its life cycle. For the dispersion and application of these insights, it is necessary to adapt them to a form, which can be used on a regular basis for the decision making of different actors in the construction sector. This implies that international efforts have to be increased with respect to:

- Definition of national standards for sustainable commercial, infrastructural and residential constructions based on LCA results
- Elaboration of good practice guidance for the optimization of processes towards 'cleaner production' for all sectors and subsectors along the life cycle of wood, and alternative materials
- Integration of environmental information in guidelines and software tools used for the planning and design by architects, building owners and contractors
- Capacity building for architects, building owners and contractors.

5 Perspectives

LCA methodology in general (the series of standards ISO 14'040ff) and its methodological development for the environmental assessment of wood products as well as the increased availability of representative and reliable LCI data has developed and been consolidated considerably in Europe and Northern America during the last decade. Thanks to this effort it has become possible to model and evaluate the environmental impacts related to the main processes and products of the wood industry. Today, more 'emotional' arguments for wood can now be supported with quantitative data in many cases and every detection and elimination of an unfavourable process within the life cycle is a contribution to a less impacted environment.

For a future use of the environmental value of wood products within a sustainable development, the general perception of the beneficiary use of wood products has to be increased at the various stages of decision-making. Key requirements to achieve this goal are reliable technical quality, economic competitiveness and a superior environmental performance. Necessary future activities to integrate 'life-cycle thinking' into an integrated product policy and to finally redirect material and energy flows into more sustainable paths are:

- Generation and maintenance of representative and reliable life cycle inventories along the wood chain – especially in countries with little experience in LCA – of new processes and technologies (e.g. end-of-pipe, waste treatment, modification of wood, new preservatives, tropical timber) and subsequent implementation of new data in respective LCA databases
- Concerted integration of regional (and temporal) aspects into LCI databases and impact assessment methodologies
- Service life prediction on the functional performance of wooden products and systems in relation to different conditions of exposure
- Elaboration of adequate product category rules (PCRs) for environmental product declarations (EPDs) based on LCA data in conformity with ISO 14'025 (see, e.g., www.gednet.org)
- Combination of LCA with other evaluation models which focus on particular aspects of forests related to the various functions and environmental services of forests, such as biodiversity/habitat, landscape, protective functions, hydrological functions, micro climate, filter against noise and dust, etc.
- Analysis and evaluation of social aspects along the wood chain (employment, health, regional policy, etc.) to support the position of wood products as indispensable element for the construction sector on its way towards sustainability.

Acknowlegements. The authors acknowledge the technical support by Carolina Ponce Alberola and Julia Ovies Pérez of the Centro Tecnológico de la Madera de Castilla La Mancha and by CONFEMADERA as well as the financial support by the Spanish Ministry of Education and Science. Also, the comments by two anonymous reviewers are gratefully acknowledged.

References

Adalberth K, Almgren A, Petersen EH (2001): Life cycle assessment of four multi-family buildings. Int J Low Energy and Sustainable Buildings 2, 1–21

Asif M, Davidson A, Muneer T (2002) Life cycle of window materials – A comparative assessment. Millenium Fellow School of Engineering, Napier University, Edinburgh, http://www.cibse.org/pdfs/Masif.pdf

Biedermann A, Carlucci L, Ackermann L, Ehrsam R, Furger G (1999): Environmental and health aspects of (solid wood) constructions (in German). Ein Forschungsauftrag von 'Holz 2000'. Institut für Baubiologie (SIB), Zürich

Bol B, Lenstra G, van Liebergen H, Paardekooper L (1995): Environment related comparative study on garden chairs (in German). Tebodin, B.V. im Auftrag des Fachverbandes Kunststoff-Konsumwaren im GKV, Frankfurt a.M.

Börjesson P, Gustavsson L (2000): Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives. Energy Policy 28, 575–588

Bowyer J, Briggs D, Lippke B, Perez-Garcia J, Wilson J (2004): Life cycle environmental performance of renewable materials in the context of residential building construction; phase I research report on the research plan to develop environmental performance measures for renewable building materials with alternatives for improved performance. Consortium for Research on Renewable Industrial Materials (CORRIM), Seattle/WA

Boyd CW, Koch P, McKean HB, Morschauer CR, Preston SB, Wangaard EF (1976): Wood for structural and architectural purposes. Forest Prod J 27, 10–20

Buchanan AH, Honey BG (1994): Energy and carbon dioxide implications of building construction. Energy and Building 20, 205–217

Buchanan AH, Levine SB (1999): Wood-based building materials and atmospheric carbon emissions. Environmental Science and Policy 2, 427–437

Ceuterick D (1993): Life cycle inventory for wall insulation products. VITO, Mol (BE)

Cole RJ (1999): Energy and greenhouse gas emissions associated with the construction of alternative structural systems. Building and Environment 34, 335–348

Consoli F, Allen D, Boustead I, Fava JA, Franklin WE, Jensen AA, de Oude N, Parrish R, Perriman R, Postlethwaite D, Quay B, Seguin J, Vigon BW (1993): Guidelines for life-cycle assessment: A code of practice. Society of Environmental Toxicology and Chemistry (SETAC), Brussels, Washington, DC

Damberger BF (1995): Comparison of 'brick constructions' with 'wood constructions' with regard to the global and regional CO_2 budged and related material and energy flows (in German). Diplomarbeit durchgeführt am Institut für Wassergüte und Abfallwirtschaft der Technischen Universität, Vienna

Erlandson M (1996): Methodology for environmental assessment of wood-based products; general and specific questions related to the life cycle inventory. Rapport I 9608070, Trätek, Stockholm

Erlandsson M, Ödeen K, Edlud M-L (1992): Environmental consequences of various materials in utility poles – A life cycle analysis. In: Proceedings of the 23. IRG Annual Meeting of IRG, IRG Doc. No. WP/3726-92, Stockholm

Esser P, Robson DJ (1999): Life-Sys wood; consistent life cycle analysis of wood products; contract No. FAIR-CT95-072; final consolidated report. TNO Centre for Timber Research, Delft

FAO (2002): Environmental and energy balances of wood products and substitutes. Food and Agriculture Organization of the United States (FAO), Rome

Fava JA, Senner J, Kirkpatrick N (1996): Life cycle inventory analysis; user's guide; enhanced methods and applications for the products of the forest industry; the international working group. American Forest & Paper Association, Washington, DC

Fossdal S (1995): Environmental impact and energy flow of building materials in Norway. In: Proceedings of the RILEM workshop on 'Environmental Aspects of Building Materials and Structures, VTT Building Technology, Technical Research Centre of Finland, Espoo, 1–9

Goedkoop M (1995): The Eco-indicator 95, final report. Netherlands Agency for Energy and the Environment (NOVEM), Ammersfoort

Goverse T, Hekkert MP, Groenewegen P, Worrel E, Smits R (2001): Wood innovation in the residential sector: Opportunity and constraints. Resources, Conservation and Recycling 34, 53–74

Günther A, Langowski HC (1997a): Life cycle assessment study of resilient floor coverings. Int J LCA 2, 73–80

Günther A, Langowski HC (1997b): Life cycle assessment study on resilient floor coverings. Fraunhofer-Institut Freising, Freising

Gustavsson L (2001): Wood vs. concrete building in a life cycle perspective. In: Merra A, Finér L, Kaila S, Karjalainen T, Mali J, Pajula T, Korhonen M (eds), COST Action E9: Life Cycle Assessment for Forestry and Forest Products, Office for Official Publications of the European Communities, Luxembourg, 79–87

Gustavsson L, Pingoud K, Sathre R (2006): Carbon dioxide balance of wood substitution: Comparing concrete- and wood-framed buildings. Mitigation and Adaptation Strategies for Global Change 11, 667–691

Harris DJ (1999): A quantitative approach to the assessment of the environmental impact of building materials. Building and Environment 34, 751–758

Heijungs R, Guinée JB, Huppes G, Lankreijer RM, Udo de Haes HA, Wegener Sleeswijk A, Ansems AMM, Eggels PG, van Duin R, de Goede HP (1992): Environmental life cycle assessment of products, guide and background. Centre for Milieukunde (CML), Leiden

Hekkert MP, Joosten LAJ, Worrel E (2000): Reduction of CO_2 emissions by improved management of material and product use: the case of transport packaging. Resources, Conservation and Recycling 30, 1–27

Hillier W, Murphey RJ, Dickinson DJ, Bell JNB (1994): Life cycle assessment and its application to preservative treated timber products. Paper presented at the WEI spring meeting. West European Institute for Wood Preservation (WEI), Brussels

Hillier W, Murphey RJ, Dickinson DJ, Bell JNB (1996): Life cycle assessment and its application to treated timber products. In: Life cycle environmental impact analysis for forest products. Forest Products Society, Madison/WI, 50–60

Hillier W, Murphy RJ, Dickinson DJ, Bell JNB (1997): The risk of life cycle impact assessment for preservative treated timber products. In: Proceedings of the WEI-Congress, WEI Document 2601, Oslo

Jönnson A (1999): Including the use phase in LCA of floor coverings. Int J LCA 4, 321–328

Jönsson A, Tillman AM, Svensson T (1994): Life cycle analysis of flooring materials. Technical Environmental Planning, Chalmers University of Technology, Göteborg

Jönsson A, Tillman AM, Svensson T (1997): Life cycle analysis of flooring materials. Building and Environment 32, 245–255

Jungmeier G (ed) (2001): Life cycle assessment of forestry and forest products; achievements of COST Action E9 working group 3 'End of life: recycling, disposal and energy generation'. Graz, Joanneum, Institute of Energy Research

Jungmeier G, Merl A, McDarby F, Gallis C, Hohenthal C, Petersen AK, Spanos K (2001): End of use and end of life aspects in LCA of wood products – Selection of waste management options and LCA integration. In: Jungmeier G (ed), Life cycle assessment of forestry and forest products; achievements of COST Action E9 working group 3 'End of life: recycling, disposal and energy generation'. Joanneum, Institute of Energy Research, Graz, 4/1–4/25

Jungmeier G, Werner F, Jarnehammer A, Hohenthal C, Richter K (2002a): Allocation in LCA of wood-based products; experiences of Cost Action E9; part I. methodology. Int J LCA 7, 290–294

Jungmeier G, Werner F, Jarnehammer A, Hohenthal C, Richter K (2002b): Allocation in LCA of wood-based products; experiences of Cost Action E9; part II. examples. Int J LCA 7, 369–375

Karjalainen T, Zimmer B, Berg S, Welling J, Schwaiger H, Finér L, Cortijo P (2001): Energy, carbon and other material flows in the life cycle assessment of forestry and forest products; achievements of the working group 1 of the COST action E9. European Forest Institute (EFI), Joensuu

Koch P (1992): Wood versus nonwood materials in U.S. residential construction: some energy related global implications. Forest Prod J 42 (5) 31–42

Kreissig J, Baitz M, Betz M, Straub W (1997): Ganzheitliche Bilanzierung von Fenstern und Fassaden. Institut für Kunststoffprüfung der Universität Stuttgart, Stuttgart

Künniger T, Richter K (1997): Environmental comparison of electricity mains made from impregnated wood, reinforced concrete and corrosion-protected steel (in German). Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Dübendorf

Künniger T, Richter K (1998): Environmental assessment of railway sleepers in Switzerland; sleepers made of prestressed concrete, profiled steel and creosote-treated beech wood (in German). Forschungs- und Arbeitsbericht 115/38, Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Dübendorf

Künniger T, Richter K (2000): Environmental assessment of constructions of garden and landscape architecture (in German). Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Dübendorf

Lenzen M, Treloar G (2002): Embodied energy in buildings: wood versus concrete – Reply to Börjesson and Gustavsson. Energy Policy 30, 249–255

LeVan S (1995): Life cycle assessment: measuring environmental impact. In: Life cycle environmental impact analysis for forest products. Forest Products Society, Madison, WI, pp 7–16

Lippke B, Wilson J, Perez-Garcia J, Bowyer J, Meil J (2004): CORRIM: Life cycle environmental performance of renewable building materials. Forest Prod J 54, 8–19

Marcea RI, Lau KK (1992): Carbon dioxide implication of building materials. Journal of Forest Engineering, 3, 37–43

Meil J, Trusty WB (1995): Life cycle assessment of buildings: an appraisal. In: Life cycle environmental impact analysis for forest products. Forest Products Society, Madison, WI, pp 17–24

Micales JA, Skog KE (1997): The decomposition of forest products in landfills. Int. Biodeterioration and Biodegradation 39, 145–158

Mötzl H, Zelger T, Gann M, Liebminger A, Lipp B (2000): Ecology of insulation materials; basics on thermal insulation, life cycle assessment, optimal insulation standards (in German). Springer Verlag Vienna, New York

Murphey RJ, Hillier W (1995): Life cycle assessment of treated wood products. In: Anonymous (ed), Wood preservation in the '90s and beyond; Proceedings No. 7308, Forest Products Society, Madison, WI, pp 49–60

Nebel B, Zimmer B, Wegener G (2006): Life cycle assessment of wood floor coverings – A representative study for the German Flooring Industry. Int J LCA 11 (3) 172–182

Nedermark R (1998): Ecodesign at Bang & Olufsen. In: Klostermann J, Tukker A (eds), Product innovation and eco-efficiency; twenty three industry efforts to reach the factor 4. Kluwer Academic Publishers, Dordrecht, Boston, London

Petersen AK, Solberg B (2003a): Environmental and economic impacts of substitution between wood products and alternative materials: A review of micro-level analyse from Norway and Sweden. Department of Forest Sciences, Agricultural University of Norway, Ås

Petersen AK, Solberg B (2003b): Substitution between floor constructions in wood and natural stone: comparison of energy consumption, greenhouse gas emissions, and costs over the life cycle. Can J for Forestry Research 33, 1061–1075

Pingoud K, Lehtilä A (2002): Fossil carbon emissions associated with carbon flows of wood products. Mitigation and Adaptation Strategies for Global Change 7, 63–83

Potting J, Blok K (1996): Life-cycle assessment of four types of floor coverings. J Cleaner Prod 3, 201–214

Reichart I, Hischier R, Schefer H, Zurkirch M (2001): Life cycle assessment of media consumption – Electronic versus paper (in German). Empa-Forschungsbericht, Eidg. Materialprüfungs- und Forschungsanstalt (Empa), St. Gallen

Ressel J (1986): Energy analysis of the wood industry in the Federal Republic of Germany (in German). Bundesministerium für Forschung und Technologie (BMFT), Hamburg

Richter K, Brunner K, Bertschinger H (1996a): Environmental assessment of thermal insulation glazing, integral comparison of different glazing variants (in German). Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Dübendorf

Richter K, Fischer M, Gahlmann H, Menard M (1995): Energy and material flows related to the production of thermal insulation materials (in German). Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Dübendorf

Richter K, Gugerli H (1996b): Wood and wood products in comparative life cycle assessment. Holz als Roh- und Werkstoff 54, 225–231

Richter K, Künniger T, Brunner K (1996c): Environmental assessment of window constructions of different frame materials (without glazing) (in German). Empa-SZFF-Forschungsbericht, Schweizerische Zentralstelle für Fenster- und Fassadenbau (SZFF), Dietikon

Schwaiger H, Zimmer B (2001): A comparison of fuel consumption and greenhouse gas emissions from forest operations in Europe. In: Karjalainen T, Zimmer B, Berg S, Welling J, Schwaiger H, Finér L, Cortijo P (eds), Energy, carbon, and other material flows in the life cycle assessment of forestry and forest products; achievements of the working group 1 of the COST Action E9. Discussion Paper 10, European Forest Institute (EFI), Joensuu

Sedjo RA (2002): Wood materials used as a means to reduce greenhouse gases (GHGS): An examination of wooden utility poles. Mitigation and Adaptation Strategies for Global Change 7, 191–200

Suzuki M, Tatsuo O, Okada K (1995): The estimation of energy consumption and CO_2 emission due to housing construction in Japan. Energy and Building 22, 165–169

Taylor J, van Langenberg K (2003): Review of the environmental impact of wood compared with alternative products used in the production of furniture. CSIRO Forestry and Forest Products Research and Development Corporation, Victoria

Townsend P, Wagner C (2002): Timber as building material – An environmental comparison against synthetic building materials. NAFI National Association of Forest Industries Ltd, Australia, http://www.nafi.com.au/files/library/TimberLCA.pdf

Werner F (1998): LCI s of insulation material – A comparison. In: Proceedings of the 10th European Conference and Technology Exhibition 'Biomass for Energy and Industry'. C.A.R.M.E.N, Würzburg, pp 180–183

Werner F (2001): Recycling of used wood – Inclusion of end-of-life options in LCA. In: Jungmeier G (ed), Life cycle assessment of forestry and forest products; achievements of COST Action E9 working group 3 'End of life: recycling, disposal and energy generation'. Joanneum, Institute of Energy Research, Graz, 6/1–24

Werner F (2002): Modelling of wooden products in life cycle assessment with special emphasis on recycling and end-of-life; model requirements, allocation procedures and recommendations derived from LCAs of railway sleepers and particleboard. Research and Work Report 115/48, Eidg. Materialprüfungs- und Forschungsanstalt (Empa), Duebendorf

Werner F (2005): Ambiguities in decision-oriented life cycle inventories; the role of mental models and values. Eco-Efficiency in Industry and Science series, vol. 17, Springer, Dordrecht

Werner F (2006): Madera en construcción en análisis de ciclo de vida comparado con productos convencionales. Werner Environment & Development, Zurich

Werner F, Althaus HJ, Richter K (2002): Post-consumer wood in environmental decision-support tools. Schweizerische Zeitschrift für Forstwesen 153, 97–106

Werner F, Althaus H-J, Richter K, Scholz RW (2007): Post-consumer waste wood in attributive product LCA; context-specific evaluation of allocation procedures in a functionalistic conception of LCA. Int J LCA 12 (3) 160–172

Werner F, Künniger T, Althaus H-J, Richter K, Jungbluth N (2003): Life cycle inventories of wood as fuel and construction material, Duebendorf, November 2002, Centre for life cycle inventories in the ETH domain, Duebendorf

Werner F, Richter K (1997a): Environmental assessment of parquet floorings; consideration of mosaic parquet, 2-layered prefabricated and 3-layered prefabricated parquets (in German). Empa/ISP-Forschungsbericht, Dübendorf, Heimberg

Werner F, Richter K (2001): Life cycle assessment of facades. In: Innovative Fassaden; Tagung Baden-Baden, 7. und 8. November 2001, VDI-Bericht 1642, VDI-Gesellschaft Bautechnik, Düsseldorf, 243–253

Werner F, Richter K, Bosshart S, Frischknecht R (1997b): Comparative LCA of doorframes made of solid wood, particle board and steel (in German). Empa/ETH-Forschungsbericht, Dübendorf, Zürich

Werner F, Taverna R, Hofer P, Richter K (2006b): Greenhouse gas dynamics of an increased use of wood in buildings in Switzerland. Climate Change 71, 319–347

Windsperger A, Piringer M, Steinlechner S (1998): Guidance flooring materials, environmental comparisons. Amt der NÖ Landesregierung, Abteilung Umweltrecht und Umweltkoordination, Pölten

Received: November 9th, 2007
Accepted: April 16th, 2007
OnlineFirst: April 17th, 2007

Appendix: Table 3

Table 3: Evaluation of relative impacts of wood products compared to products made of conventional materials. Evaluation: ++: very positive (< 50% of average impact); +: positive (50% to 90% of average impact); 0: average (90% to 110% of average impact); -: negative (110% to 150% of average impact); - -: very negative (> 150% of average impact). Abbreviations: NonR: non-renewable energy; Ren: renewable energy; CED: cumulated energy demand; GWP 100: global warming potential (100 years); AP: acidification potential; EP: eutrophication potential; POP: photochemical ozone formation potential (photosmog); ODP: (stratospheric) ozone depletion potential; ETW: eco-toxicity potential water; ETS: eco-toxicity potential soil; HT: human toxicity potential; RA: radioactivity; CS: carcinogenic substances; HM: heavy metals

	Energy			CML92/Ecoindicator 95											Waste			Crit. Vol.	
	NonR	Ren	CED	GWP	AP	EP	POP	ODP	ETW	ETS	HT	RA	CS	HM	Solid	Reac.	Haz.	Air	Water
Windows (Richter et al. 1996./Brunner et al. 1996I)																			
Wood/Alu			+	+	+	+	+	+	+		-				+	++	-		
Wood/Alu			+	+	++	+	+	+	+		-				+	++	- -		
Aluminium			0	0	0	0	0	0	-		+				0	+	+		
Steel			-	0	0	-	-	-	-		0				-	0	- -		
Stainless steel			-	-	- -	-	-	-	-		0				- -	-	++		
Non-ferrous steel			-	- -	-	-	-	-	-		0				-	- -	+		
PVC			+	+	0	0	0	+	+		+				+	+	+		
Insulation materials (Mötzl et al. 2000)																			
Wood fibre board	++	- -		++	++	++	++		++		++								
Glass wool	-	+		- -	- -	- -	-		+		-								
Cellulose fibres	++	++		++	++	++	++		++		++								
Perlite	++	++		+	++	++	++		++		++								
EPS	- -	++		- -	- -	- -	- -		- -		- -								
Foamglass	- -	+		- -	- -	- -	+		0		- -								
Mineral wool	+	++		0	+	+	++		+		+								
Vermiculite	++	++		++	+	+	++		+		+								
Floorings (Günther et al. 1997)																			
Parquet (3-layers)	+	- -	-	- -	++											++	++		
Linoleum	+	-	+	-	+											+	++		
Extruded PVC	0	++	+	+	0											+	- -		
PVC	-	++	0	+	0											0	- -		
Polyolefins	0	+	0	+	++											0	++		
Rubber	0	+	0	+	- -											-	+		
Textile flooring	-	++	-	+	++											++	++		
Flooring (Jönsson 1999/Windsperger 1998)																			
Parquet	++			++	+	-	++								++	++	++		
Linoleum	-			+	+	0	- -								++	-	- -		
PVC	-			- -	- -	+	0								- -	- -	0		
Wall constructions (Werner et al. 1996)																			
Wood frame				++	+	++	++	++	+	++	+								
Laminated timber board				++	-	+	+	+	- -	+	-								
Brick wall, 2-layered				- -	- -	- -	-	-	-	-	-								
Porous cement bricks				-	0	0	0	-	0	-	0								

Table 3 (*cont'd*): Evaluation of relative impacts of wood products compared to products made of conventional materials. Evaluation: ++: very positive (< 50% of average impact); +: positive (50% to 90% of average impact); 0: average (90% to 110% of average impact); -: negative (110% to 150% of average impact); - -: very negative (> 150% of average impact). Abbreviations: NonR: non-renewable energy; Ren: renewable energy; CED: cumulated energy demand; GWP 100: global warming potential (100 years); AP: acidification potential; EP: eutrophication potential; POP: photochemical ozone formation potential (photosmog); ODP: (stratospheric) ozone depletion potential; ETW: eco-toxicity potential water; ETS: eco-toxicity potential soil; HT: human toxicity potential; RA: radioactivity; CS: carcinogenic substances; HM: heavy metals

	Energy			CML92/Ecoindicator 95											Waste			Crit. Vol.	
	NonR	**Ren**	**CED**	**GWP**	**AP**	**EP**	**POP**	**ODP**	**ETW**	**ETS**	**HT**	**RA**	**CS**	**HM**	**Solid**	**Reac.**	**Haz.**	**Air**	**Water**
Doorframes (Werner et al. 1996)																			
Particleboard	+	- -	0	0	0	0	0	0				0	+	++					
Solid wood	+	-	+	+	+	++	+	+				0	++	++					
Galvanized Steel	-	++	-	-	- -	- -	-	-				0	- -	- -					
Railway sleepers (Künniger et al. 1998)																			
Beech wood			-	0	-	0		-							0	-	0		
Steel			+	0	0	0		0							0	0	0		
Concrete			+	0	+	0		0							+	+	0		
Utility poles (Künniger et al. 1997)																			
Roundwood CCF	++	- -	+	++	++	+	+								++				
Concrete	+	++	+	+	+	0	+								- -				
Tubular steel	- -	++	- -	- -	- -	-	- -								+				
Elements of landscape architecture (Künniger et al. 2000)																			
Swings: wood			+	+	+	+	+	+	- -	+	-								
Swings: steel			-	-	-	-	-	-	+	-	+								
Swings: steel (with duplex)			-	-	-	-	-	-	+	++	+								
Palisades: wood			-	++	+	+	+	+	- -	0	- -								
Palisades: concrete			+	- -	-	-	-	-	++	++	++								
Blinds: wood (vertical filling)			+	++	++	++	++	++	-	-	++								
Blinds: wood (diagonal filling)			+	++	++	+	++	++	- -	-	+								
Blinds: lime stone bricks			-	-	-	-	- -	- -	+	++	-								
Blinds: bricks			-	- -	- -	- -	- -	-	+	++	- -								
Blinds: concrete			0	-	-	-	0	-	+	++	-								
Posts vineyard : roundwood			-	+	++	++	+	+	-	++	-								
Posts vineyard : quart. roundw.			+	+	++	++	+	+	- -	++	-								
Posts vineyard : reinf. concrete			0	-	-	-	- -	- -	++	++	+								
Posts vineyard : galv. steel			-	-	- -	- -	0	-	+	- -	+								
Posts fruit yard: roundwood			+	+	+	+	+	+	- -	++	-								
Posts fruit yard: quart. roundw,			+	+	+	+	+	+	- -	++	-								
Posts fruit yard: PVC			+	0	0	+	-	+	++	++	+								
Posts fruit yard: galv. steel			- -	- -	- -	- -	-	-	+	- -	+								
Residential houses (Boyer et al. 2004/Lippke et al. 2004)																			
Cold climate; wood			0	+											0			0	++
Cold climate; steel			0	-											0			0	- -
Warm climate; wood			0	+											+			+	0
Warm climate; concrete			0	-											-			-	0